DENVER FRONT RANGE STUDY
DIOXINS IN SURFACE SOIL

Study 3: Western Tier Parcel
Rocky Mountain Arsenal

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LIST OF ACRONYMS AND ABBREVIATIONS

Ah	aryl hydrocarbon
ATSDR	Agency for Toxic Substances and Disease Registry
CAS	Columbia Analytical Services
COC	Contaminant of Concern
D/F	dioxin/furan
EMPC	Estimated Maximum Potential Concentration
HRGC/MS	High Resolution Gas Chromatography/Mass Spectrometry
LCS	Laboratory Control Sample
MDL	Method Detection Limit
MQL	Method Quantitation Limit
MRI	Midwest Research Institute
NPL	National Priority List
OCP	organochlorine pesticide
PARCC	Precision, Accuracy, Representativeness, Comparability, and Completeness
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PE	Performance Evaluation
ppt	parts per trillion (1 microgram per kilogram)
QA/QC	Quality Assurance/Quality Control
QATS	Quality Assurance Technical Support
RMA	Rocky Mountain Arsenal
RPD	Relative Percent Difference
SOP	Standard Operating Procedure
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TEF	Toxicity Equivalency Factor
TEQ	2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents
TOC	Total Organic Carbon
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WTP	Western Tier Parcel

LIST OF CHEMICAL ABBREVIATIONS

HpCB	heptachlorobiphenyl
HpCDD	heptachlorodibenzodioxin
HpCDF	heptachlorodibenzofuran
HxCB	hexachlorobiphenyl
HxCDD	hexachlorodibenzodioxin
HxCDF	hexachlorodibenzofuran
OCDD	octachlorodibenzodioxin
OCDF	octachlorodibenzofuran
PeCB	pentachlorobiphenyl
PeCDD	pentachlorodibenzodioxin
PeCDF	pentachlorodibenzofuran
TCB	tetrachlorobiphenyl
TCDD	*2,3,7,8*-tetrachlorodibenzo-*p*-dioxin
TCDF	tetrachlorodibenzofuran

1.0 INTRODUCTION

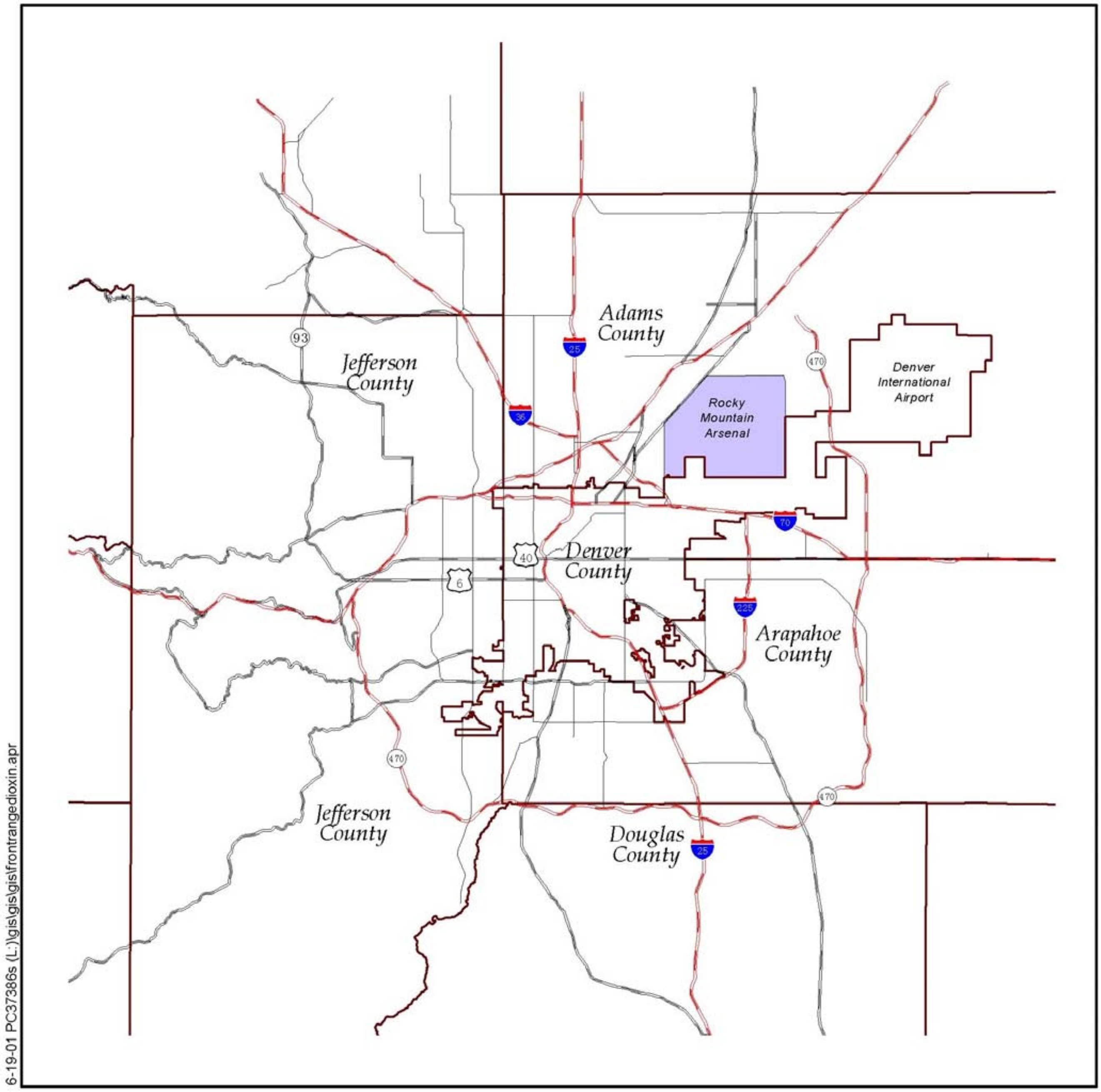
1.1 Site Description

The Rocky Mountain Arsenal (RMA) is a parcel of approximately 27 square miles of land located north-east of Denver, Colorado (see Figure 1). The RMA was previously used by the US Army for manufacturing and testing of munitions, and was subsequently used by Shell Oil Company for the manufacture of pesticides. Because of extensive chemical contamination in the central portion of the site, the United States Environmental Protection Agency (USEPA) became involved in studies to clean up RMA in 1982, and the site was placed on National Priorities List (NPL) in 1987. The chemicals of principal health concern at RMA vary from location to location, and include pesticides, metals, solvents, chemical process intermediates, and chemical warfare agents. In particular, several organochlorine pesticides (OCPs), mainly aldrin and dieldrin, are major contaminants of concern (COCs), as well as a number of their intermediates and degradation products (USEPA 1999b).

In October 1992, in recognition of the unique urban wildlife resources within RMA, President George Bush signed into law the Rocky Mountain Arsenal National Wildlife Refuge Act of 1992, making RMA a National Wildlife Refuge once remediation was completed. Section 5 of the Refuge Act anticipated that an area of real property located in the western tier of RMA (referred to as the Western Tier Parcel or WTP) would be sold in advertised sales as surplus property under the provisions of the Federal property and Administrative Services Act of 1949. Because the On-Post Record of Decision (FWEC 1996) did not identify any remedial action for soil within the WTP, the WTP has been under consideration for deletion from the NPL in anticipation of its sale for commercial development.

Earlier site investigations at RMA suggested that contamination levels in the WTP are below a level of concern (EBASCO 1991, EBASCO 1994, USEPA 1998c). This conclusion was based on a relatively limited data set for the WTP, and did not include a consideration of all potential future land uses. In order to evaluate the potential human risk from soil contaminants in the WTP in greater detail, USEPA Region 8 collected additional surface soil samples from the WTP and analyzed them for certain OCPs and metals (USEPA 1999b). This study found very low concentrations of these contaminants in the WTP (most were well below USEPA's current levels of health concern), supporting the previous conclusion that the parcel is safe for sale and unrestricted development (USEPA 2000a).

Figure 1. Location of the Rocky Mountain Arsenal



Subsequently, some members of the public stated they were still concerned that the RMA (and hence the WTP) might be contaminated with dioxins. A review of this question was performed by Gannett Fleming (1999), and USEPA Region 8 concluded that data available at the time were insufficient to determine whether dioxins should or should not be considered chemicals of potential concern at RMA. For this reason, the current study was planned and performed to characterize the concentrations of dioxins in WTP surface soils and to compare those concentrations to USEPA's human-health-based reference values for screening risk-based soil concentrations (USEPA 1998a).

1.2 Definition of Dioxins

"Dioxin" is usually used as a synonym for *2,3,7,8*-tetrachlorodibenzo-*p*-dioxin (TCDD). The toxicity of TCDD is believed to be initiated by binding of the TCDD molecule to a cellular protein referred to as the aryl-hydrocarbon (Ah) receptor. However, there are many different chemicals besides TCDD that can bind to this receptor and trigger some or all of the toxic responses that are associated with TCDD exposure. This includes some other members (congeners) of the polychlorinated dibenzodioxin (PCDD) class, as well as some polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), other types of halogenated (e.g., brominated) dioxins and furans, as well as various other chlorinated hydrocarbons (e.g. chlorinated naphthalenes). For the purposes of this report, the term "dioxins" is meant to refer to the set of 29 congeners in the polychlorinated dioxin/furan/biphenyl group that bind to the aryl hydrocarbon (Ah) receptor and possess toxic characteristics similar to those of *2,3,7,8*-tetrachlorodibenzo-*p*-dioxin (TCDD). These 29 congeners are listed in Table 1.

In this study and report, greatest emphasis is placed on the 17 PCDD and PCDF congeners with TCDD-like activity, since PCBs are not considered to be chemicals of concern at RMA, and because the current USEPA soil screening levels for dioxins (USEPA 1998a) are based only upon these congeners. However, the 12 PCB congeners with TCDD-like activity were included in the study and analyses for reasons of a) completeness for background characterization, and b) to help resolve mass-balance comparisons with TCDD bioassays that were conducted for RMA tissue samples and which could be performed (if needed) on soil samples.

Table 1. List of Analytes and TEFs

Class	Target Analyte	TEF		
		Mammals	Birds	Fish
Polychlorinated Dibenzo-p-dioxins (PCDDs)	2,3,7,8-TCDD	1	1	1
	1,2,3,7,8-PeCDD	1	1	1
	1,2,3,4,7,8-HxCDD	0.1	0.05	0.5
	1,2,3,6,7,8-HxCDD	0.1	0.01	0.01
	1,2,3,7,8,9-HxCDD	0.1	0.1	0.01
	1,2,3,4,6,7,8-HpCDD	0.01	< 0.001	0.001
	OCDD	0.0001	0.0001	<0.0001
Polychlorinated Dibenzofurans (PCDFs)	2,3,7,8-TCDF	0.1	1	0.05
	1,2,3,7,8-PeCDF	0.05	0.1	0.05
	2,3,4,7,8-PeCDF	0.5	1	0.5
	1,2,3,4,7,8-HxCDF	0.1	0.1	0.1
	1,2,3,6,7,8-HxCDF	0.1	0.1	0.1
	1,2,3,7,8,9-HxCDF	0.1	0.1	0.1
	2,3,4,6,7,8-HxCDF	0.1	0.1	0.1
	1,2,3,4,6,7,8-HpCDF	0.01	0.01	0.01
	1,2,3,4,7,8,9-HpCDF	0.01	0.01	0.01
	OCDF	0.0001	0.0001	<0.0001
Polychlorinated Biphenyls (PCBs)	3,3',4,4'-TCB (77)	0.0001	0.1	0.0005
	3,4,4',5-TCB (81)	0.0001	0.05	0.0001
	3,3',4,4'-5-PeCB (126)	0.1	0.1	0.005
	3,3',4,4',5,5'-HxCB (169)	0.01	0.001	0.00005
	2,3,3',4,4'-PeCB (105)	0.0001	0.0001	< 0.000005
	2,3,4,4',5-PeCB (114)	0.0005	0.0001	< 0.000005
	2,3',4,4',5-PeCB (118)	0.0001	0.00001	< 0.000005
	2',3,4,4',5-PeCB (123)	0.0001	0.00001	< 0.000005
	2,3,3',4,4',5-HxCB (156)	0.0005	0.0001	< 0.000005
	2,3,3',4,4',5'-HxCB (157)	0.0005	0.0001	< 0.000005
	2,3',4,4',5,5'-HxCB (167)	0.00001	0.00001	< 0.000005
	2,3,3',4,4',5,5'-HpCB (189)	0.0001	0.00001	< 0.000005

TEF = Toxicity Equivalency Factor
TEF values are consensus estimates recommended by WHO (Van den Berg et al. 1998)

Relative Toxicity of Dioxin Congeners

Dioxins are of potential health concern because they may pose an increased risk of cancer and other non-cancer adverse health effects at extremely low levels of exposure. However, not all dioxin congeners are equally toxic. The relative toxicologic potency of a congener, compared to that of the most toxic form (*2,3,7,8*-TCDD), is expressed in terms of the Toxicity Equivalency Factor (TEF). Table 1 lists the current consensus TEF values for mammals (including humans), birds, and fish. These TEF values were developed by a panel of experts assembled by the World Health Organization (WHO) (Van den Berg et al. 1998), and have been adopted for use by the USEPA (USEPA 2000b). It should be noted that TEFs are often based on limited data, and so they are recommended for use as only approximations of the relative toxicity of each congener, rounded to the nearest half order of magnitude.

Calculation of TCDD-Equivalents (TEQ) in Soil

The aggregate toxicity of a mixture of different dioxins in an exposure medium (soil, food web items, water, etc.) is a complex function of the following variables:

a) the concentration of each congener in the medium
b) the chronic average daily intake of the medium
c) the absorption of each congener from that medium
d) the toxicokinetics (distribution, metabolism, and elimination) of the congeners
e) the relative biological potency of the congeners

Thus, calculation of health risk from exposure to soil that contains a mixture of congeners must take all of these variables into account. However, for purposes of screening-level evaluations of dioxin concentrations in soil samples, it is usually most convenient to calculate the concentration of TCDD-Equivalents (TEQ) present in the soil as the TEF-weighted sum of each of the 29 dioxin-like congeners (17 dioxins and furans, plus 12 PCBs), as follows:

$$\text{TEQ(total)} = \sum_{i=1}^{29} (C_i \cdot \text{TEF}_i)$$

In cases where interest is focused on the contribution of PCDDs and PCDFs only (i.e., PCBs not included), the value is calculated as:

$$\text{TEQ(D / F)} = \sum_{i=1}^{17} (C_i \cdot \text{TEF}_i)$$

It is important to understand that this application of TEFs to the calculation of soil TEQ values is appropriate only for screening level purposes. This is because TEFs are derived from, and thus should only be applied to, biological endpoints (e.g., embryotoxicity). The soil TEQ approach does not account for the potential influences of differential absorption, metabolism, distribution, and excretion of different congeners from soil, and risk assessors should account for these uncertainties in the interpretation of the soil TEQ values.

1.3 Human Health Based Reference Values for Dioxins in Soil

The USEPA has currently established a default concentration value of 1,000 parts per trillion (ppt) TEQ in surface soil as a concentration that is not of cancer or non-cancer concern for lifetime exposure of residents (USEPA 1998a), even when no other site-specific data are known. For commercial and industrial land uses, USEPA guidelines identify 5,000 to 20,000 ppt TEQ as the concentration of concern in soil. These soil screening concentrations are based only upon the 17 TCDD-like PCDDs and PCDFs, calculated using the TEFs for mammals recently recommended by the WHO (Van den Berg et al. 1998).

The Agency for Toxic Substances and Disease Registry (ATSDR) has also established an interim policy guideline for human (residential) exposure to dioxin and dioxin-like compounds in soil (De Rosa et al. 1997). ATSDR identifies a concentration of 50 ppt TEQ in soil as a "screening level," below which no further investigation or characterization will usually be required. ATSDR identifies a concentration of 1,000 ppt TEQ as an "action level," indicating that public health actions such as surveillance, research, health studies, community education, or exposure investigations should be considered. Concentrations between 50 ppt and 1000 ppt TEQ are identified as "evaluation levels," indicating that further investigation of site-specific factors regarding the extent and possible public health implications of the exposure may be warranted.

The USEPA is in the process of completing a comprehensive reassessment of dioxin toxicity, and has tentatively concluded that the carcinogenic and non-carcinogenic potency of dioxins may be somewhat greater than previously believed (USEPA 2000b). However, until a complete peer review and cross-program policy assessment of the impacts of this report can be performed, USEPA recommends that the 1,000 ppt TEQ concentration in surface soil continue to be used as a soil screening level for residential land uses (USEPA 1998a), and that 5,000 ppt TEQ be used as a frame of reference for assessing exposure of commercial workers.

With respect to the WTP, it is expected that most of the site will be developed for commercial purposes, so a value of 5,000 ppt TEQ is likely to be appropriate for most locations. However, because future development at the site could include facilities such as a child daycare center, risk managers have decided that the residential screening value of 1,000 ppt TEQ in soil will be retained in order to be maximally protective.

2.0 METHODS

A detailed description of the rationale, methods, and Standard Operating Procedures (SOPs) used in this study is provided in the Project Plan for the study (USEPA 1999a). A summary of key elements of the study design and of the methods employed is presented below.

2.1 Sampling Locations

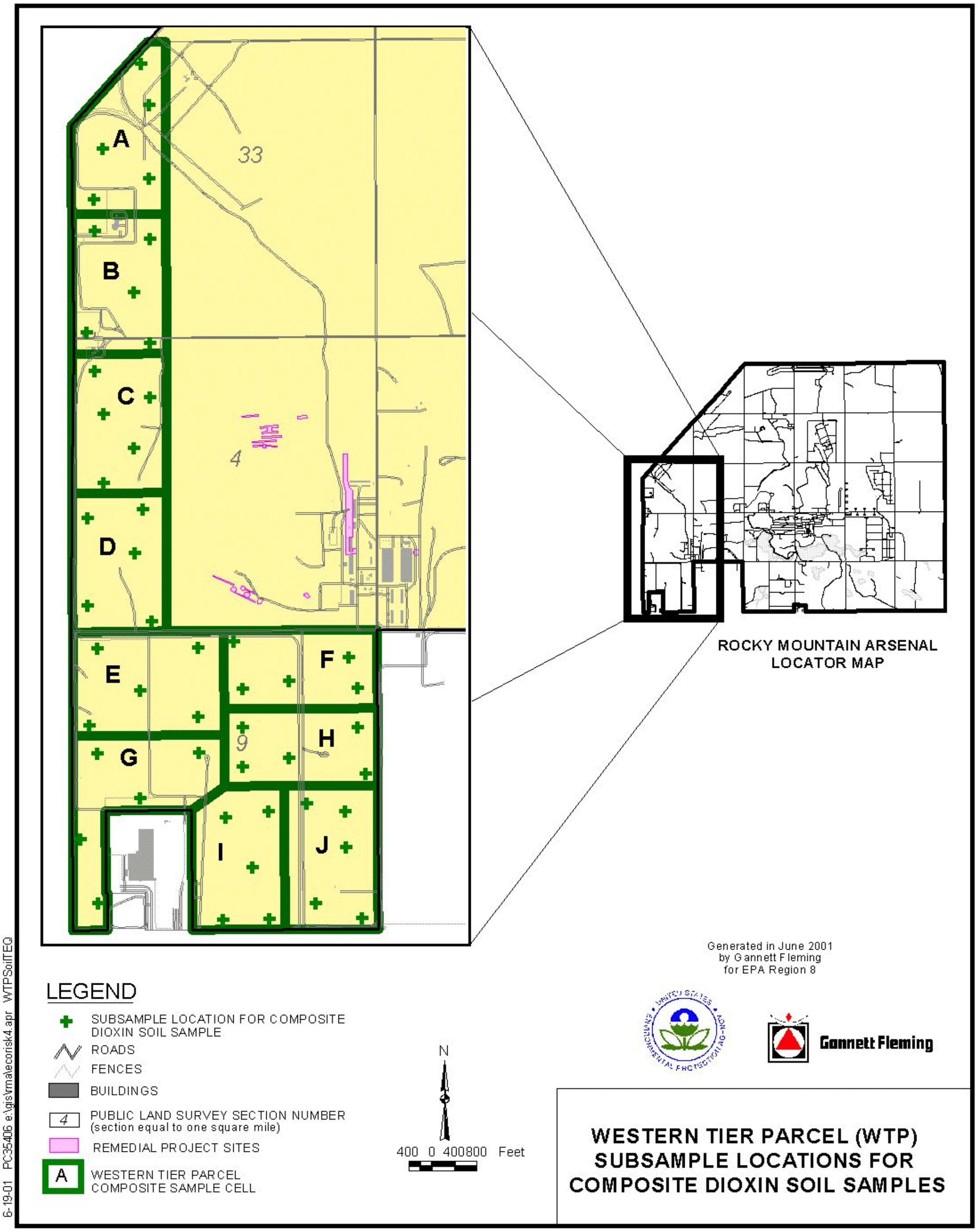
For the purpose of evaluating the potential health risks from dioxins in surface soils, the WTP was subdivided into 10 sub-parcels of approximately 90 acres each. Within each sub-parcel, a set of five surface soil (0 to 2 inches) samples were collected using a stratified random sampling scheme to ensure spatial representativeness of the samples. These 10 sub-parcels and the locations of the five surface soil samples within each sub-parcel are shown in Figure 2. Exact sampling locations were selected that had soil which appeared to be undisturbed and were judged to be characteristic of the sub-parcel. Photographs were taken and descriptions of each sub-sample site were recorded, and sampling locations were surveyed to an accuracy of 0.1 foot in accord with standard practice for all sampling activities at RMA. Appendix C contains a map that shows the sample identification number for each sample, along with a table that lists the coordinates of each sample.

2.2 Sample Collection and Storage

Because dioxins nearly always bind tightly to soil, it is expected that any dioxin contamination in soil attributable to atmospheric fallout, application of pesticides, or surface disposal of dioxin-contaminated material will be restricted mainly to the surface. Thus, surface soil is the exposure medium of chief concern for both human and ecological receptors. Therefore, all soil samples collected for this study were grab samples collected at 0-2 inches in depth.

Samples were collected using clean techniques that included use of disposable stainless steel trowels (one per sampling location) and plastic gloves. A ruler was used to ensure that the actual depth to which soil was collected was within ½ inch of the target (i.e., a bottom depth of no less than 1.5 inches and no greater than 2.5 inches). Loose debris and most gravel or pebbles were removed from the soil sampling site. The surface soil was placed directly into a clean 16-

Figure 2. Location of the Western Tier Parcel



ounce amber glass jar, filled to capacity (about 500 grams of soil), sealed with a teflon-lined lid, and stored in these bottles at room temperature in the dark until shipped in sealed plastic coolers with frozen ice-packs and water temperature tubes that helped ensure no excess heating occurred during transportation to the processing laboratory.

2.3 Sample Preparation

All soil samples collected in the field were submitted under chain-of-custody to Columbia Analytical Services (CAS) for sample preparation. Each sub-sample from a sub-parcel was air-dried and weighed, followed by coarse-sieving through a #10 (2 millimeter) stainless steel screen. The fraction passing the coarse screen was referred to as the "bulk" fraction. About 100 grams of mixed bulk soil from each of the five sub-samples for a sub-parcel was then combined to produce a composite sample of about 500 grams to represent the sub-parcel surface soil. After mixing the composite bulk soil, approximately 26 grams of the bulk composite sample was placed in a clean amber glass jar and stored for possible future use. The remainder of the composited bulk sample was further sieved through a 60-mesh (250 micrometer) stainless steel screen in order to isolate soil particles less than 250 micrometers in diameter. This is referred to as the "fine" fraction. The fine-sieved soil samples were thoroughly mixed, and placed into four new amber sample bottles, with each bottle containing about 26 grams of the fine-sieved composited soil. These four aliquots of fine-sieved soil were intended to be as identical as possible, for use in reanalysis (if needed) and for establishing intra-laboratory and inter-laboratory reproducibility (precision) for quality control purposes. The remainder of each sub-sample soil fraction was retained and stored under chain of custody by USEPA Region 8, in case there was a need to analyze any of the individual sub-samples separately. All processed soil samples were sent under chain of custody to the USEPA Regional Laboratory in Golden, CO, for storage and for organization of samples for later shipments to the analytical laboratory in Kansas City, MO.

The "fine" fraction was isolated for chemical analysis because it is believed that fine soil particles can electrostatically adhere to skin and thus are more likely be ingested by hand to mouth contact than coarse particles. Hence it is concluded that the fine soil fraction is the most relevant media for use in evaluating human health risk. The bulk soil samples were retained for purposes of evaluating the potential enrichment of TEQ concentrations in the fine-sieved fraction due to small soil particles having greater surface to mass ratios than their bulk soil counterparts. It should be noted that most historic soil sampling studies for dioxins have only evaluated bulk soils, and so consideration needs to be given when comparing historic bulk dioxin results and the results for dioxin TEQs in this study's fine soil samples. If enrichment is present, it would cause the fine soil fractions to have greater concentrations of TEQs than their corresponding bulk counterparts, and bulk soil results would tend to underestimate exposure.

2.4 Sample Analysis

Following sample preparation as described above, samples were submitted by USEPA Region 8 under chain of custody to Midwest Research Institute (MRI) for congener-specific analysis of PCDDs, PCDFs, and PCBs. This type of analysis requires sophisticated extraction and clean-up procedures to accurately measure all of the various forms of PCDDs, PCDFs, and PCBs, as detailed in Standard Operating Procedure 11 of the Project Plan USEPA (1999a). In brief, the congeners are determined using an isotope dilution method via high resolution gas chromatography/mass spectrometry (HRGC/HRMS). Samples are fortified with known quantities of ^{13}C-labeled PCDD/PCDF/PCB isomers and extracted with organic solvents, using two columns so that all 12 PCBs can be retained for analysis. Before cleanup of the extracts, the analytes are exchanged into hexane and fortified with ^{37}Cl-labeled *2,3,7,8*-tetrachlorodibenzo-*p*-dioxin. Finally, the extracts are sequentially partitioned against concentrated acid and base solutions.

The Method Detection Limit (MDL) for this study-specific analytical method was defined as an analyte signal that was 2.5 times the average background signal ("noise"). An estimate of the average signal noise is available for each analyte in each sample, so the MDL varies from sample to sample and from analyte to analyte. The Method Quantitation Limit (MQL) is based partly on the lowest calibration standard used, and was defined as a signal that was 10-times the average signal noise. Because the noise level varied from sample to sample and analyte to analyte, MDLs and MQLs also varied from sample to sample and from congener to congener. Most PCDD/PCDF congeners had MQL values between 0.5 and 2.5 ppt, and most PCB congeners had MQLs between 2 and 12 ppt.

2.5 Quality Assurance

A number of steps were taken to obtain data that would allow an assessment of the quality and reliability of the data collected, so that assessments of the scientific usability of the data could be made and defended. The analytical laboratory routinely processed and analyzed “lots” (batches) of 20 samples at a time. Of these 20 samples, two were used for laboratory control samples (LCS) and blanks. Therefore, 18 samples were usually available for USEPA to submit to MRI as a batch. In general, these 18 samples were comprised of 14 field samples plus four Quality Control (QC) samples, as described below.

Performance Evaluation Samples

Performance Evaluation (PE) samples are samples of soil that contain known quantities of analyte and that are submitted blind to the analytical laboratory. In this study, three different PE samples were used. These were obtained from USEPA's Quality Assurance Technical Support (QATS) laboratory. Nominal values (ppt as TEQ in bulk soil, based on the 17 PCDD/PCDF congeners only) are listed below:

Table 2. Nominal TEQ(D/F) Concentrations in PE Samples

PE Sample (Bulk Soil)	**Nominal TEQ(D/F) (ppt)**
Native western soil (estimated value)	< 2
Low standard (certified value)	35
Medium standard (certified value)	59

One aliquot of each these three PE samples from QATS was submitted to the laboratory along with each batch of field samples.

Field Splits and Duplicates

A field duplicate is a second sample of soil collected simultaneously with the first sample. In this case, field duplicates were collected by alternating scoops of soil into two bottles with separate and random sample identification numbers. A field split is a sample that is generated by dividing a single field sample into two parts. As described above, in this study every field sample was dried and sieved by CAS, and this fine material was divided into four essentially identical aliquots of 26 grams each. EPA Region 8 selected random samples to submit as split samples, and a second bottle of these samples was assigned a new random sample identification number and submitted in random order for analysis by MRI. Analysis of these types of samples provided data on the variability within and between related samples. One sample of this type (either field split or field duplicate) was submitted to the laboratory (blind) with each set of 14 field samples.

Laboratory Quality Control Samples

Internal laboratory quality control samples are samples prepared and run by the laboratory in a non-blind fashion to monitor the performance of the analytical method. Laboratory QC samples included Method Blanks (analyte-free soil), Laboratory Control Samples (similar to PE samples, but the identity and true concentration are known to the laboratory), and optionally Method Duplicates (investigative samples that are split prior to sample preparation at the analytical laboratory). As noted above, two samples in each batch were used by the laboratory for laboratory QC samples.

2.6 Data Validation/Verification

Validation of analytical results was conducted according to SOP 803 (revision 1) of the Project Plan (USEPA 1999a). This validation method was tailored to match the site-specific method used to analyze the 29 dioxin-like congeners in soils. An independent contract chemist team, with expertise in validation of PCDD, PCDF, and PCB analytical results, conducted the analytical reviews. For the WTP, full validation was performed for all samples.

Major analytical factors and QA/QC performance were reviewed against defined Precision, Accuracy, Representativeness, Comparability, and Completeness (PARCC) criteria to ensure that results were reliable and usable for the objective identified in the Project Plan . Narratives were produced for each analytical lot to describe the results of the data validation for that lot. Each data value (i.e., each concentration value) was assigned a data usability flag, if needed, using the data quality flag codes presented in Table 3. In accordance with USEPA data usability guidelines (USEPA 1992), these flags were used for producing two alternative data sets:

1) a semi-quantitative set of results in which congeners that yielded signals below the sample-specific detection limit for that congener (signal/noise ratio less than 2.5) were evaluated by assuming a concentration value equal to ½ the detection limit for that congener, and other flagged data were adjusted according to the rules shown in Table 3. This is referred to in this report as the "**Full**" data set.

2) a quantitative set of results based only on those congeners that have no disqualifying flags (D, NJ, R and LT), or have adjusted quantitative values as described in Table 3. This is referred to in this report as the "**Quant**" data set.

Table 3. Definition, Application, and Uses of Data Flags

Validation Flags	Meaning of Flags for Dioxin Analyses in Soils and Tissues by the MRI Lab	Data Usability (a) **Full** data set used (*semi-quantitative*)	 **Quantitative** (qualified sub-set used)
E	Estimated Maximum Potential Concentration; the relative ion abundance ratios did not meet the acceptance limits.	use value	use ½ value
D	EMPC is caused by polychlorinated **D**iphenyl ether interference.	use ½ value	don't use
B	Analyte was detected in associated Method **B**lank, sample concentration <5x MB concentration.	use value	use ½ value
C	Concentration is above upper **C**alibration Standard; result is an estimate, flagged C by lab and J added by validator.	use value	use value
I	Recovery of 13C-labeled **I**sotopic analyte outside of criteria	use value	use value
J	Estimated: e.g., isotopic standard is outside CCAL range, native analyte recovery in LCS is outside criteria, etc.	use value	use ½ value
NJ	Presumptive evidence for the presence of an analyte with an estimated value; if used for 2378-TCDF, see "U" below.	use ½ value	don't use
S	Peak is **S**aturated; result, if calculated, is flagged by the validator as an estimate - "J".	use value	use value
U	**U**nconfirmed: column is not specific for 2,3,7,8-TCDF; confirmation not requested. Validator now uses "NJ" flag.	use value	use ½ value
R	**R**ejected: result is invalid and not usable.	use ½ MDL	don't use
***use of MRI Laboratory's reported "LT" (less than) values* <MQL (10 x Signal:Noise)**			
LT *applied **first** to data, then apply flags!*	"LT" is not a true "flag", but if a LT result is a "**detect**" **above the MDL** (2.5 x Signal:Noise = lab EDL), then	use value	use ½ value
	"LT" is not a true "flag", but if a LT result is a "**non-detect**" **below the MDL** (2.5 x Signal:Noise = lab EDL), then	use ½ EDL	don't use

(a) In accord with concepts in the 1992 EPA Data Usability for Risk Assessment in Superfund guidance (USEPA 1992), data quality flags are used to produce two data-sets: 1) a "**Full**" set of semi-quantitative results with an **actual** or a **proxy** value for each of the measured congeners; and 2) a more "Quantitative" but limited set of results that has more certain identification and more accurate quantities of congeners which have **no disqualifying flags** (D, NJ, R or LT), but can use **limited proxies** (E, B, J or U). This distinction is made to better understand and limit artifactual impacts of the *less certain **estimated** values* on TEQs, analyzing the degree of this sensitivity to trace-level "noise" by comparing TEQs from these two data sets. In addition, congener profile pattern analysis should only use the analytes that are quantifiable (above the MQL).

These two datasets were prepared to help evaluate the magnitude of effects of estimated values from the Full dataset on TEQs, and to show how the quantitative subset of results can be properly derived to statistically evaluate the profiles of congeners in soils. In general, the Full TEQ(D/F) results are considered to be the most relevant in evaluating potential health risks from dioxins.

3.0 RESULTS

Detailed analytical results for each field sample are presented in Appendix A1, and detailed results for each QA sample run as part of this study are presented in Appendix A2. Graphical representations are presented in Appendix B. The results are summarized below.

3.1 Data Validation Results

Full validation of the data for the WTP site found the analytical results to be usable, as qualified with the appropriate data quality flags, except for one sample that failed to meet acceptable QC criteria. The sample from sub-parcel B (sample 911) was noted to have elevated detection limits (mostly for furans). These detection limits were considerably outside the target MDLs for the study and were roughly 10 fold higher than MDLs for the same congeners in other soil samples in the same lot. Therefore, another 26 gram aliquot of this soil sample was resubmitted in the usual blind and random manner for re-analysis. The results from analysis of this sample (assigned the number 911-R) yielded MDLs for the congeners that were substantially improved when compared to the original analysis, and so the results for 911-R were used for the WTP study, instead of the initial rejected results for sample 911.

3.2 TEQ Values in Field Samples

The results (expressed as ppt TEQ) for each of the 10 WTP composited soil samples are summarized in Table 4 and are shown graphically in Figures 3 and 4.

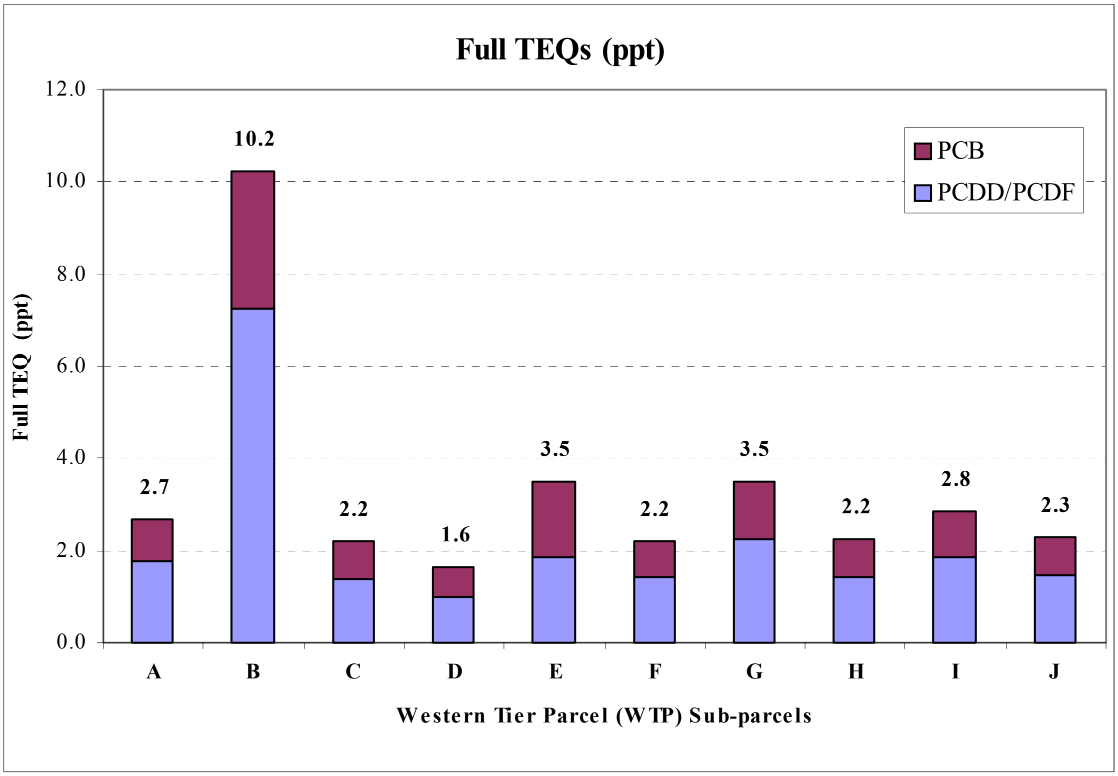
As seen in the upper panel of Figure 3, Full TEQ values for PCDDs and PCDFs alone (i.e., not including PCBs) ranged from 1.0 to 2.2 ppt in most samples, with one sample (sub-parcel B) being somewhat higher (7.2 ppt). The Full TEQ values, when summed across PCDDs/PCDFs and including PCBs, ranged from 2.6 to 3.5 ppt for most areas, with sub-parcel B again being somewhat higher (10.2 ppt). The mean Full TEQ(D/F) concentration averaged across all sub-parcels was 2.2 ppt, and was 3.3 ppt when PCBs were included.

Table 4. TEQ Values for WTP Soil Samples

Sample Description	PCDD/PCDF		PCB		ALL	
	Full	Quant	Full	Quant	Full	Quant
Sub-parcel A	1.8	0.5	0.9	0.9	2.7	1.4
Sub-parcel B	7.2	7.1	3.0	2.8	10.2	9.9
Sub-parcel C	1.4	0.4	0.8	0.8	2.2	1.2
Sub-parcel D	1.0	0.3	0.6	0.6	1.6	0.9
Sub-parcel E	1.9	0.7	1.6	1.6	3.5	2.3
Sub-parcel F	1.4	0.7	0.8	0.8	2.2	1.4
Sub-parcel G	2.2	0.9	1.3	1.2	3.5	2.1
Sub-parcel H	1.4	0.6	0.8	0.8	2.2	1.4
Sub-parcel I	1.9	0.7	1.0	0.9	2.8	1.6
Sub-parcel J	1.5	0.8	0.8	0.8	2.3	1.6
All (average)	2.2	1.3	1.2	1.1	3.3	2.4

All TEQ values are expressed in units of ppt
Full = TEQ calculated based on all congeners, assuming ½ the MDL for congeners below the MDL
Quant = TEQ calculated based only on congeners detected above the MQL

Figure 3. TEQ Values for WTP Soils



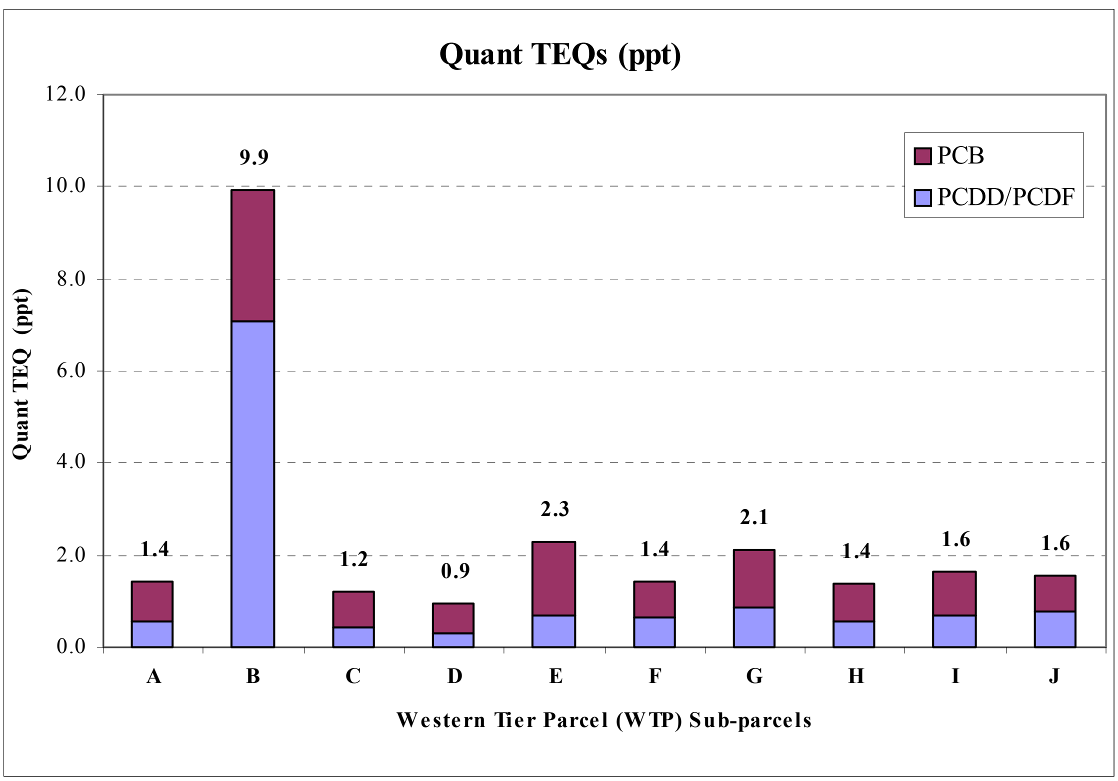
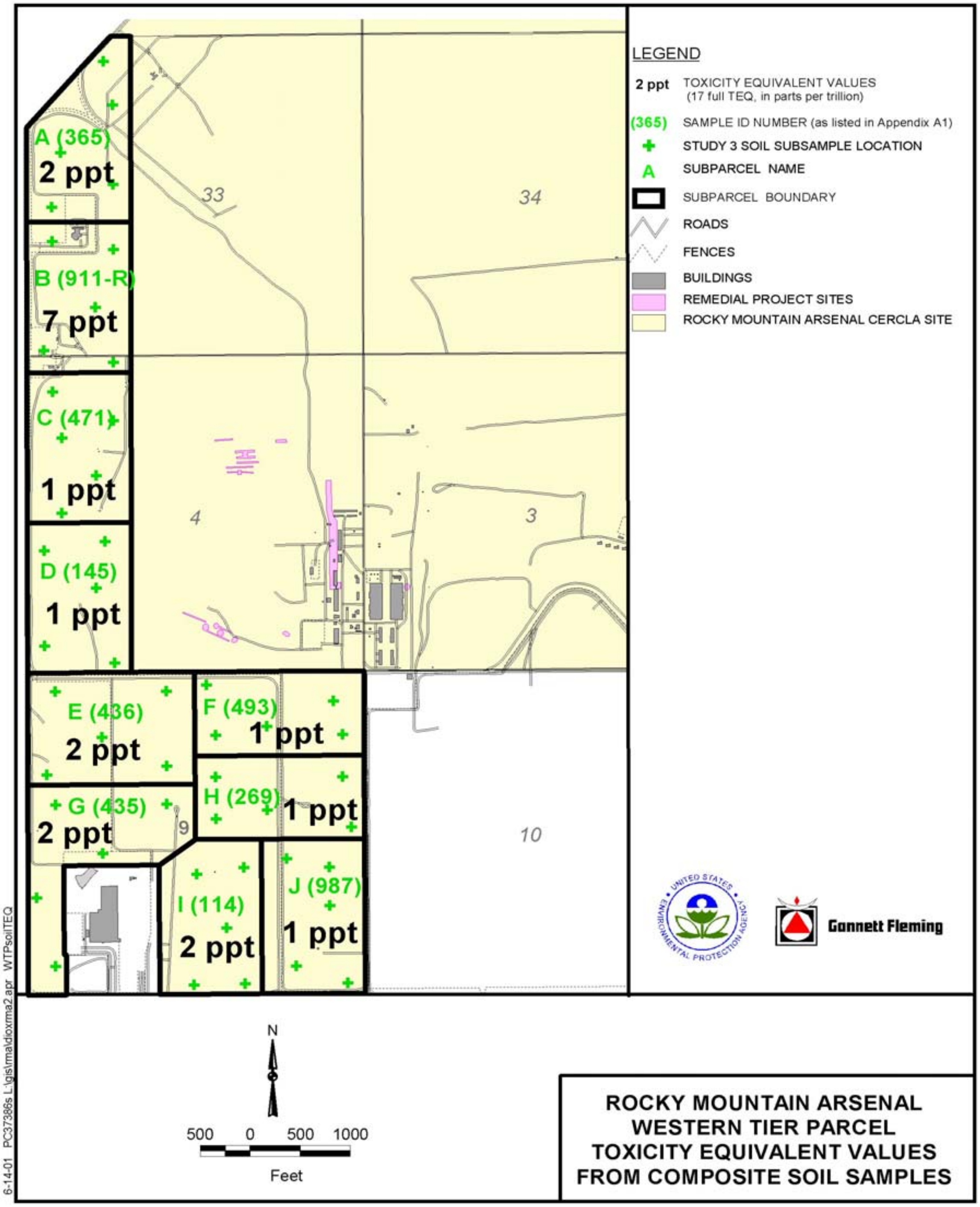


Figure 4. Map of Full TEQ (17 DFs) Results for WTP Soils



As shown in the lower panel of Figure 3, Quant TEQ values for PCDDs and PCDFs alone (without PCBs) ranged from 0.3 to 0.9 ppt in most samples, with sub-parcel B remaining somewhat higher at 7.1 ppt. The Quant TEQ values, when summed across PCDDs/PCDFs and including PCBs, ranged from 0.9 to 2.3 ppt for most areas, with sub-parcel B again being somewhat higher (9.9 ppt). The mean Quant TEQ(D/F) concentration averaged across all sub-parcels was 1.3 ppt, and was 2.4 ppt when PCBs were included. As can be observed by comparing the Full with the Quant results, inclusion of proxy (substitute) values in the Full dataset, for either qualified data or for results less than the MDL, caused the mean TEQ to increase by about 0.1-1 ppt (40-70%) when compared to the Quant dataset, and inclusion of PCBs also increased the mean TEQs for either dataset by about 0.3-2 ppt. Thus, use of proxy values and inclusion of PCBs contribute a relatively small absolute increment to TEQ values in WTP soils.

The source of the relatively greater (but only slightly elevated) concentrations of PCDDs/PCDFs and PCBs in sub-parcel B is not known; however, this same area had similar slight elevations in aldrin and dieldrin concentrations that were found in the earlier 1999 study by USEPA Region 8 (USEPA 2000a).

3.3 Comparison to Risk-Based Guidelines

In accordance with the Project Plan developed before implementation of this study, the potential health risk to humans from future exposures to dioxins in soil was evaluated by comparing the TEQ concentration value in each composite sample with the USEPA default health-based reference value of 1,000 ppt for residential scenarios. As seen, none of the WTP samples (including the sample from sub-parcel B) approached this health-based value, indicating that dioxins do not pose a human health concern for any of the sub-parcels in the WTP. Likewise, none of the samples exceed the ATSDR screening concentration of 50 ppt TEQ, which is a level below which ATSDR does not generally recommend any further investigation or analysis (De Rosa et al. 1997).

One potential limitation of this conclusion is that the soil samples being compared to the EPA or ATSDR guideline are all composites; that is, the concentration value for a composite might be determined by one high sub-sample value mixed with four lower values. This is not of concern for cases where a sub-parcel is an exposure unit, since it is the mean value, not individual sub-sample values, within an exposure unit that is the determinant of human health risk. However, if any particular sub-parcel were further sub-divided for development, then the mean concentration in that smaller exposure unit might be higher than the composite for the sub-parcel. The highest possible concentration that could occur in any one sub-sample of a 5-point composite is five-times the composite value (assuming that all four of the other sub-samples had a concentration of zero). However, even in this worst case scenario, the highest Full TEQ(D/F) that could have occurred in any sub-sample (that for sub-parcel B) is 35 ppt TEQ(D/F), which is still far below the action level of 1,000 ppt established by EPA and ATSDR. Indeed, it is even below the screening level of 50 ppt established by ATSDR. This worst case calculation indicates that there are no locations in the WTP that approach a level of human health concern.

Should the pending dioxin reassessment (USEPA 2000b) result in a policy that recommends or establishes a lower risk-based soil concentration some time in the future, the levels of dioxin TEQs observed in the WTP are still not likely to be a cause for concern, since the TEQ concentrations are not appreciably different from the ambient background levels in Denver or elsewhere in the USA (see Section 4.1).

3.4 Contribution of PCBs

Figure 3 illustrates how the Full TEQ(total) is distributed between the two main classes of dioxin congeners; i.e., the 17 PCDDs and PCDFs and the 12 PCBs. As seen, in most samples the contribution of PCBs to the Full TEQ(total) was about 30-40%, with an average contribution across all WTP samples of about 36%. That is, of the Full TEQ(total) observed in WTP samples, about 60-70% is due to PCDDs and PCDFs. This relationship is similar for the TEQs derived from the Quant dataset.

3.5 Contribution of Congeners Below the Quantitation Limit

As noted above, in the calculation of the Full TEQ value for a sample, all congeners that were below the detection limit (signal/noise ratio < 2.5) were evaluated by assuming a concentration value equal to ½ the detection limit. This is the approach is that is normally used to evaluate chemicals of concern at Superfund sites (USEPA 1989). In order to evaluate the relative contribution of congeners that were either not detected, or else were present at such low concentrations that their true concentration could only be estimated, a second calculation of "Quant" TEQ was performed, which included only those congeners that were detected above the quantitation limit (signal/noise > 10). Other occasional adjustments to reported concentrations of congeners were made when certain qualifier flags were assigned to the result, based on the criteria shown in Table 3.

Based on the data in Table 4, it is seen that for most samples (all but sub-parcel B), the contribution of congeners that were below the quantitation limit accounted for about 30-40% of the Full TEQ (total), with an average across all WTP samples of about 36%. If PCBs are excluded, the contribution of PCDDs and PCDFs below the quantitation limit accounted for about 56% of the Quant TEQ(D/F). Although this contribution of congeners below the quantitation limit introduces some uncertainty into the calculated Full TEQ values, this should not be important in risk-management decision making because all of the TEQ values are well below the USEPA soil screening level of 1000 ppt in soil for residential scenarios.

3.6 Comparison of Bulk to Fine Samples

As noted earlier, all samples were prepared by sieving to isolate the "fine" fraction of particles less than 250 micrometers in diameter, since it is believed that this size fraction is likely to be of greater relevance to human exposure than the bulk fraction. However, since most other studies of dioxin concentrations in soil have used un-sieved soil, several samples of bulk soil were also analyzed to allow a comparison of concentration values in the bulk and fine fractions. The results are summarized below.

Table 5. Comparison of TEQ Concentrations in Bulk and Fine Soil Samples

Data Set	Sample	TEQ(D/F) (ppt)			TEQ(total) (ppt)		
		Bulk	Fine	Ratio(a)	Bulk	Fine	Ratio(a)
Full	Sub-parcel I	1.9	1.9	1.0	2.5	2.9	1.2
	Low Standard	45.5	71.6	1.6	46.0	72.3	1.6
	Medium Standard	85.6	123.6	1.4	92.6	133.1	1.4
Quant	Sub-parcel I	1.0	0.7	0.7	1.7	1.6	0.9
	Low Standard	34.5	54.2	1.6	35	54.6	1.6
	Medium Standard	68.6	99.9	1.5	75.4	109.2	1.5

Ratio = Fine/Bulk

As seen above, even though data are available for only three samples, the results suggest that the concentrations of dioxins may be up to 60% higher in the fine fraction than in the bulk fraction. This effect is more apparent in the two QATS standards than in the field sample. It is not known whether this is because the enrichment is easier to measure in the QATS sample (because their concentrations are significantly higher than the near detection limit concentration in the field sample from sub-parcel I), or whether this is an attribute of the QATS samples that is not shared by the field sample. If enrichment of dioxins in the fine fraction of field samples does occur, then evaluations of dioxin TEQs that are based only on analyses of bulk samples may tend to underestimate human health risk.

3.7 Quality Control Samples

Quality control samples that were analyzed as part of this study indicate that the data are reliable and accurate.

Method Blanks

Two laboratory method blanks were included for the samples associated with this study. The values for Full TEQ(total) were 0.2 ppt and 0.6 ppt, with an average of 0.4 ppt. The corresponding Quant TEQ(total) were 0.0 ppt and 0.1 ppt. These results indicated that there was no significant source of PCDD, PCDF, or PCB contamination within the laboratory.

Laboratory Spikes

Two different laboratory spikes were analyzed in association with the field samples from the WTP. Spike concentrations were 20 ppt for TCDD and TCDF, 100 ppt for each of the penta-, hexa- and hepta-PCDDs and PCDFs, and 200 ppt for OCDD, OCDF, and each of the PCBs. Based on this spiking mixture, the nominal TEQ(D/F) is 250 ppt, and the nominal TEQ(total) is 272.5 ppt. Recovery of individual PCDD/PCDF congeners ranged from 62% to 119%, with an average across both samples of 95%. Recovery of individual PCBs ranged from 92% to 136%, with an average across both samples of 107%. When expressed as Full TEQ, recovery was 96% to 102% for TEQ(D/F) and 97% to 102% for TEQ(total). This indicates that matrix interference is not likely to be of concern.

Splits and Duplicates

TEQ(D/F) values for duplicate and split samples are as follows:

Table 6. Comparison of Results for Split and Duplicate Samples

Sample	Full TEQ(D/F)		Quant TEQ(D/F)	
Sub-parcel C Sub-parcel C Split	1.4 1.1	Delta = 0.3	0.4 0.5	Delta = 0.1
Sub-parcel F Sub-parcel F Duplicate	1.4 1.1	Delta = 0.3	0.7 0.3	Delta = 0.4
Clean PE soil (fine)	2.0 1.1	Delta = 0.9	1.4 0.9	Delta = 0.5

Sample	Full TEQ(D/F)		Quant TEQ(D/F)	
Low PE Soil (fine)	71.6 70.8 72.5	RPD = 2%	54.2 70.4 72.1	RPD = 19%
Medium PE soil (fine)	123.6 126.0	RPD = 2%	99.9 122.7	RPD = 20%

As seen, for samples with low TEQ values, the average absolute difference between samples pairs is only 0.1 to 0.9 ppt TEQ, well within the acceptability criterion of 1 MQL (about 5 ppt TEQ) that was established by the Project Plan (USEPA 1999a). For samples with TEQ values above the MQL, the Relative Percent Difference (RPD) ranges from 2% to 20%, also well within the acceptance criterion of 30% established by the Project Plan (USEPA 1999a).

Performance Evaluation Samples

Analytical results for the soil performance evaluation (PE) samples obtained from the USEPA QATS (quality assurance technical support) laboratory are summarized below.

Table 7. Evaluation of Accuracy Using Certified PE Samples

PE Sample	Certified Conc. (ppt)	Measured TEQ (ppt)			
		TEQ(D/F) (ppt)		TEQ(Total) (ppt)	
		Full	Quant	Full	Quant
Low Standard (bulk)	35	45.5	34.5	46.0	35.0
Medium Standard (bulk)	59	85.6	68.6	92.6	75.4

As seen, the measured values for TEQ(D/F) in the bulk fraction are in reasonable agreement with the nominal values (also based on bulk soil), especially when congeners that are present below the quantitation limit are not included in the TEQ calculation (i.e., Quant TEQs). In the low standard, measured values of TEQ(total) are only slightly higher that for TEQ(D/F), indicating only a low level (less than 1 ppt TEQ) of PCB contamination is present. However, in the Medium Standard, PCB contamination is higher (about 7-8 ppt TEQ). The congener pattern in these PE samples is shown graphically in Appendix B4.

As noted above, two samples of the "Clean Soil" PE sample provided by the QATS laboratory were also analyzed. This is the soil used by QATS contractors for spiking with TCDD-like congeners to produce the PE standard soils. This soil sample was estimated to contain less than 2 ppt TEQ in the bulk fraction, but this was not a certified value. The samples of Clean Soil analyzed in this study were sieved to isolate the fine fraction before analysis, so the expected value in the fine fraction is not known. However, both analytical results were low (2.0 and 1.4 ppt Full TEQ(total) and 1.1 and 0.9 ppt Quant TEQ(total)), consistent with the estimated values in the bulk soil. Because these samples were submitted to CAS in parallel with field samples, these results establish that there is no significant source of contamination during the sample preparation or the sample analysis steps.

4.0 DISCUSSION

4.1 Comparison of WTP to Background

Dioxins can be formed and released to the environment from a variety of sources, especially incinerators that burn medical and municipal wastes (USEPA 1994). In addition, dioxins can be formed in low levels from the combustion of coal and wood, and dioxins are released from power plants, wood burning furnaces, forest fires, etc. (USEPA 1998b). As a consequence of these multiple and widespread sources, dioxins are believed to be present in low concentrations in nearly all samples of surface soil.

Limited data are available in the literature on the concentrations of PCDDs and PCDFs in "background" soil. Data from studies that measured the concentrations of all of the toxicologically relevant *2,3,7,8*-substituted PCDD and PCDF congeners are summarized in Table 8. Results are presented as average ppt TEQ, calculated using the WHO consensus TEF values for mammals (Van den Berg et al. 1998). Non-detects were evaluated by assuming a value of zero, so the results are approximately equivalent to the "Quant" TEQ values calculated in this report. As seen, mean values for rural and urban areas are mainly in the 1-6 ppt range, although some lower and some higher values are reported. The range of individual sample values in a study is generally much wider than the range of mean values between studies. For example, the range reported in the BC Environment (1995) study was from less than 1 ppt to 57 ppt (mean = 4 ppt). Likewise, Rotard et al. (1994) reported a range of 1-6 ppt in grassland and plowland, and from 6-150 ppt in forest. Thus, the mean values reported in Table 8 should not be interpreted as defining the range of concentrations that occur in individual grab samples. In addition, it is important to emphasize that all of these literature values should be interpreted with caution, since there are a number of limitations that exist with some of these studies. This includes lack of raw data, uncertainties in detection limits, land uses, sampling methods and depths, and quality assurance of the data. Nevertheless, despite these uncertainties in the literature values, it appears that average concentrations within the WTP (mean Quant TEQ(D/F) = 1.3) are not higher than expected for rural background soils.

Table 8. Summary of Background Concentrations of Dioxins and Furans(a)

Category	Reference	Location	Number of samples	Comments	Mean TEQ (b)
Rural	BC Environment, 1995	British Columbia	53	background	4
	Kjeller et al., 1991	England	3	agricultural, average of 3 samples taken in 1986, excluded all historic samples	2
	MRI, 1992	Connecticut	34	background	6
	Reed et al., 1990	Minnesota	4	semi-rural, background, but near former site of coal-fired power plant	4
	Rogowski and Yake, 1999	Washington	54	agricultural	<1
	Rogowski et al., 1999	Washington	16	rangeland and forest	2
	Rotard et al., 1994	Germany	41	grassland, plowland forest (hardwood, conifer)	3 42
	Schuhmacher et al., 1997	Catalonia, Spain	30	rural samples near where a hazardous waste incinerator is under construction	1
	Rappe and Kjeller, 1987	Europe	3	rural areas from "various parts of Europe"	2
	Tewhey Associates, 1997	Maine	8	background	3
	US EPA, 1996	Ohio	3	background	1
Urban	NIH, 1995	Maryland	37	urban	2
	US EPA, 1996	Ohio	18	urban	21
	Rogowski et al., 1999	Washington	14	urban	4
	Schuhmacher et al., 1997	Catalonia, Spain	10	urban samples near where a hazardous waste incinerator is under construction	5
Industrial	Rappe and Kjeller, 1987	Europe	2	industrial areas from "various parts of Europe"	166

(a) Adapted from USEPA (2000b)
(b) TEQ values calculated using WHO consensus TEF values for mammals (Van den Berg et al. 1998). All values rounded to the nearest ppt to account for uncertainties in the measurements.

Recently, the USEPA Region 8 has completed a large study on background dioxin concentrations in surface soils at multiple locations around the Denver Front Range area. The details of this study will be presented elsewhere (USEPA 2001), and the results are presented in Appendix D. Summary statistics for fine soils are as follows:

Table 9. Dioxin Levels Measured in Denver Front Range Soils

Land Use	Sample Size	Full TEQ (D/F)	
		Mean	Range
Open Space	37	1.6	0.1-9.1
Agricultural	27	1.6	0.1-7.7
Residential (a)	37	7.1	0.2-43
Commercial (b)	30	6.4	0.4-57
Industrial	29	9.8	0.2-54
All combined (a,b)	160	5.3	0.1-57

(a) One outlier value (155 ppt TEQ) excluded (see USEPA 2001)
(b) One outlier value (140 ppt TEQ) excluded (see USEPA 2001)

Using the Open Space land use as the most appropriate frame of reference for past land use at the WTP, it is seen that levels on the WTP are nearly identical to the off-post TEQ concentrations. The mean Full TEQ(D/F) for WTP was 1.6 ppt for all sub-parcels except for sub-parcel B, and was 2.2 ppt for all sub-parcels including sub-parcel B. The mean Quant TEQ(D/F) for WTP was 0.7 ppt for all sub-parcels when excluding sub-parcel B, and 1.3 ppt including sub-parcel B. Even the highest WTP concentration of 7 ppt in sub-parcel B falls within the range of both the Denver Front Range background TEQs as well as roughly within the ranges for background reported in the literature.

4.2 Congener Composition

The congener composition of a soil sample may provide useful information about the source of the dioxin contamination, and helps to reveal which specific congeners are contributing the majority of the risk.

Appendix A shows the relative (percent) contribution of each of the 29 congeners to the total TEQ in each of the samples from the WTP. The mean contribution of each congener (percent contribution within a sample averaged across all samples) to TEQ is summarized in Table 10. As seen, most of the Full TEQ(total) is contributed by PCB-126, *1,2,3,7,8*-PeCDD,

Table 10. Average Contribution of Congeners to TEQ(Total)

Congener	Full TEQ(Total)	Quant TEQ(Total)
2,3,7,8-TCDF	1%	0%
2,3,7,8-TCDD	4%	0%
1,2,3,7,8-PeCDF	1%	1%
2,3,4,7,8-PeCDF	12%	7%
1,2,3,7,8-PeCDD	13%	5%
1,2,3,4,7,8-HxCDF	5%	4%
1,2,3,6,7,8-HxCDF	3%	2%
2,3,4,6,7,8-HxCDF	3%	2%
1,2,3,7,8,9-HxCDF	2%	2%
1,2,3,4,7,8-HxCDD	2%	3%
1,2,3,6,7,8-HxCDD	4%	6%
1,2,3,7,8,9-HxCDD	3%	4%
1,2,3,4,6,7,8-HpCDF	1%	0%
1,2,3,4,7,8,9-HpCDF	0%	0%
1,2,3,4,6,7,8-HpCDD	10%	9%
OCDF	0%	0%
OCDD	1%	1%
PCB-77	0%	0%
PCB-81	0%	0%
PCB-105	0%	1%
PCB-114	0%	0%
PCB-118	1%	1%
PCB-123	0%	0%
PCB-126	31%	50%
PCB-156	1%	1%
PCB-157	0%	0%
PCB-167	0%	0%
PCB-169	0%	0%
PCB-189	0%	0%

2,3,4,7,8-PeCDF, and *1,2,3,4,6,7,8*-HpCDD. TCDD itself contributes only an average of 4% of the total based on the Full analysis, and this contribution decreases to zero when only analytes above the MQL are considered (the Quant TEQ). The results for PCDDs/PCDFs only (PCBs excluded) are summarized in Table 11. As seen, the main sources of Full TEQ(D/F) from this group are *2,3,4,7,8*-PeCDF, *1,2,3,7,8*-PeCDD, and *1,2,3,4,6,7,8*-HpCDD. Based on Quant TEQ(D/F), the contributions of TCDD and TCDF decrease to zero and the relative contributions of the two hexachlorodibenzodioxins become more significant.

Appendix B1 presents a series of graphs showing the absolute chemical concentrations and TEQ contributions of each of the 29 congeners in each of the 10 WTP soil samples. Appendix B2 shows the aggregate concentrations and TEQ contributions for each of the five homologue classes of the 17 TCDD-like dioxins and furans. Appendix B3 shows the relationships between aggregate concentrations and TEQ contributions of dioxins compared to furans. Appendix B4 presents similar concentration graphs for QA samples. In all cases, greater emphasis is placed on the quantitative concentration data than the full concentration data for evaluation of congener concentration profiles.

Inspection of these graphs reveals that most of the WTP samples have a similar "fingerprint" of congeners. The congeners present in the highest concentrations typically include OCDD, PCB-118 and PCB-105, with lower amounts of *1,2,3,4,6,7,8*-HpCDD, OCDF, PCB-77, PCB-126, PCB-156 and PCB-167. Figure 5 summarizes the quantitative congener concentration pattern in WTP soils. The upper panel shows congeners in the PCDD/PCDF class, while the lower panel shows congeners in the PCB class. As seen in the upper panel, the primary D/F congener is usually OCDD, along with lower amounts of OCDF and hepta-CDD. As seen in the lower panel, several PCBs are usually present, primarily 77, 105, 118, 156, and 167.

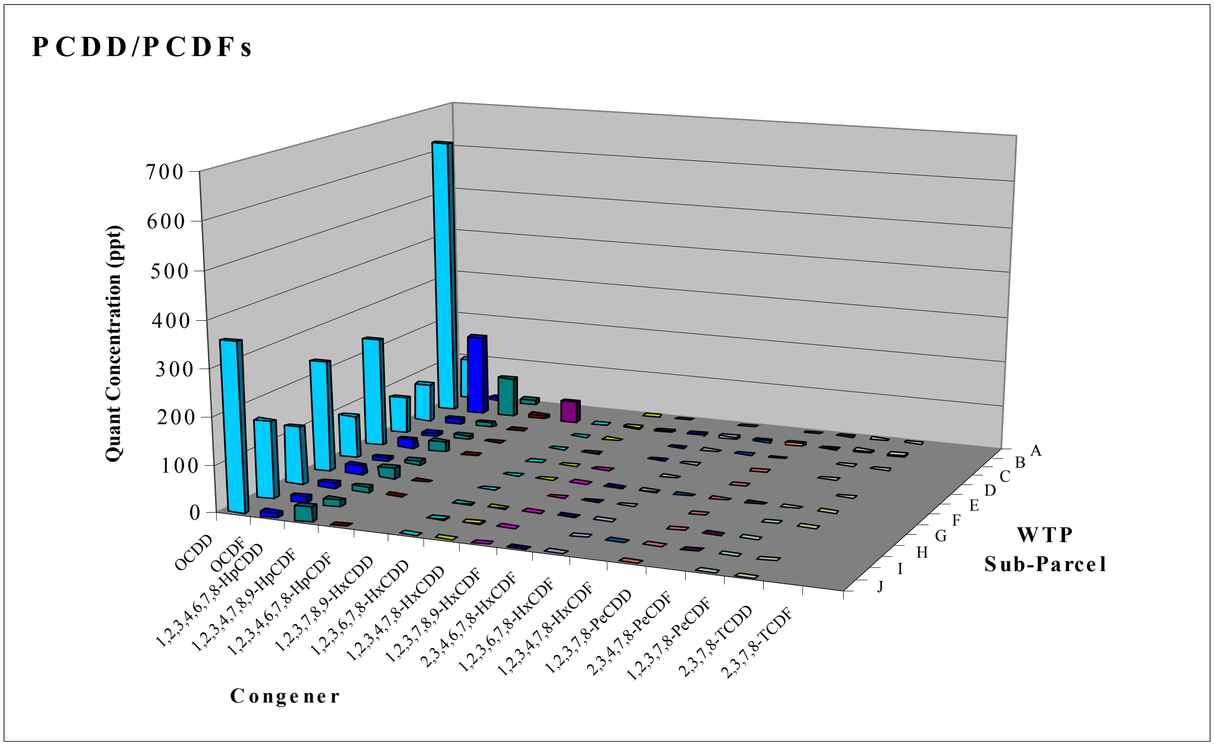
As noted earlier, TEQ values are moderately elevated in sub-parcel B compared to other WTP sub-parcels. The relative congener pattern for sub-parcel B is generally similar to that seen for the other sub-parcels, although the ratio of hepta-PCDD/PCDFs to octa-PCDD/PCDFs and the ratio of total PCDFs to total PCDDs are both somewhat higher for the sample from sub-parcel B than for the other sub-parcels in the WTP (see Appendices B2 and B3). However, it is not possible to identify the likely source of the added contamination in sub-parcel B based on the available data.

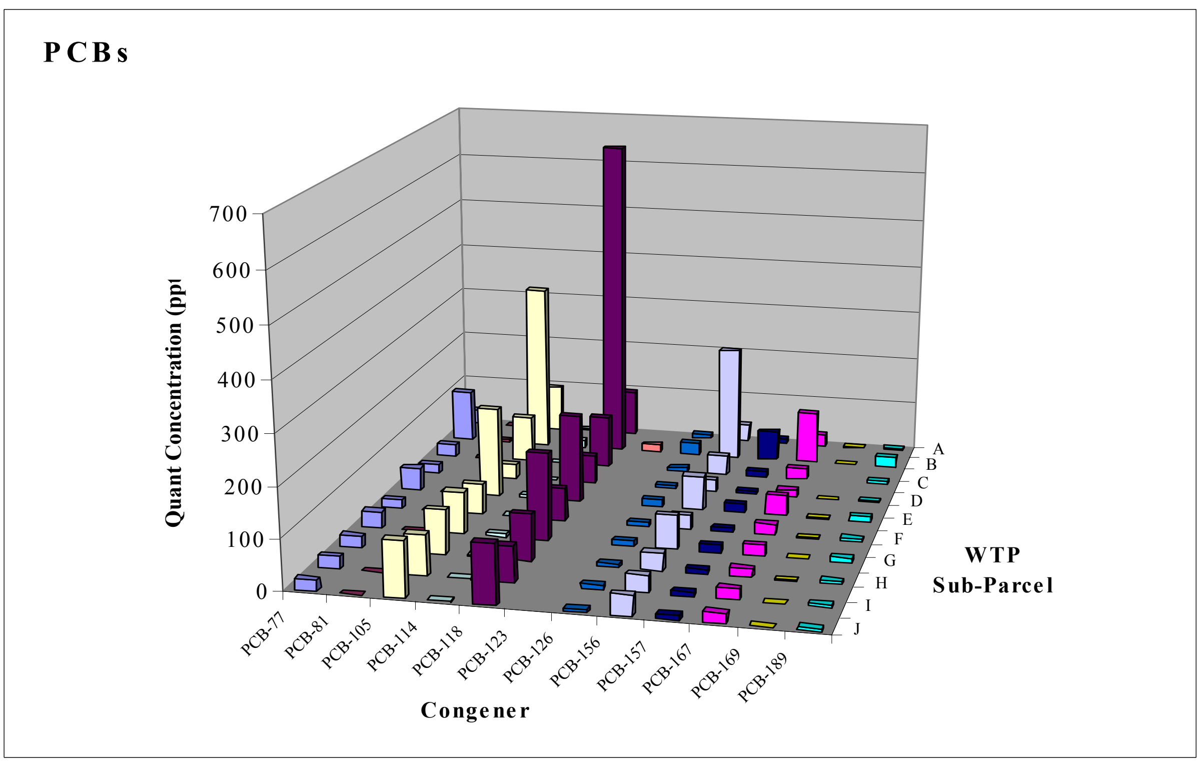
A more detailed and quantitative analysis of the congener concentration values in surface soil samples from the WTP, other locations within the RMA, and from multiple locations and land uses around the Denver Front Range area will be presented in a subsequent report.

Table 11. Average Contribution of Congeners to TEQ(D/F)

Congener	Full TEQ(D/F)	Quant TEQ(D/F)
2,3,7,8-TCDF	1%	0%
2,3,7,8-TCDD	6%	0%
1,2,3,7,8-PeCDF	1%	1%
2,3,4,7,8-PeCDF	18%	14%
1,2,3,7,8-PeCDD	21%	11%
1,2,3,4,7,8-HxCDF	5%	5%
1,2,3,6,7,8-HxCDF	4%	2%
2,3,4,6,7,8-HxCDF	5%	4%
1,2,3,7,8,9-HxCDF	3%	3%
1,2,3,4,7,8-HxCDD	3%	6%
1,2,3,6,7,8-HxCDD	6%	15%
1,2,3,7,8,9-HxCDD	5%	12%
1,2,3,4,6,7,8-HpCDF	2%	1%
1,2,3,4,7,8,9-HpCDF	0%	0%
1,2,3,4,6,7,8-HpCDD	17%	24%
OCDF	0%	0%
OCDD	2%	2%

Figure 5. Congener Concentration Patterns





4.3 Dependence of TEQ on Soil Characteristics

Binding of dioxins to soil particles is a physical process that might be expected to depend on the total organic carbon (TOC) content of the soil, as well as the surface-area-to-mass ratio (i.e., the particle size distribution). Such a dependence of TEQ levels on soil characteristics has been noted by Rogowski et al. (1999), although these data are somewhat limited by use of TEQ values calculated from congener concentrations that were largely below the MDL.

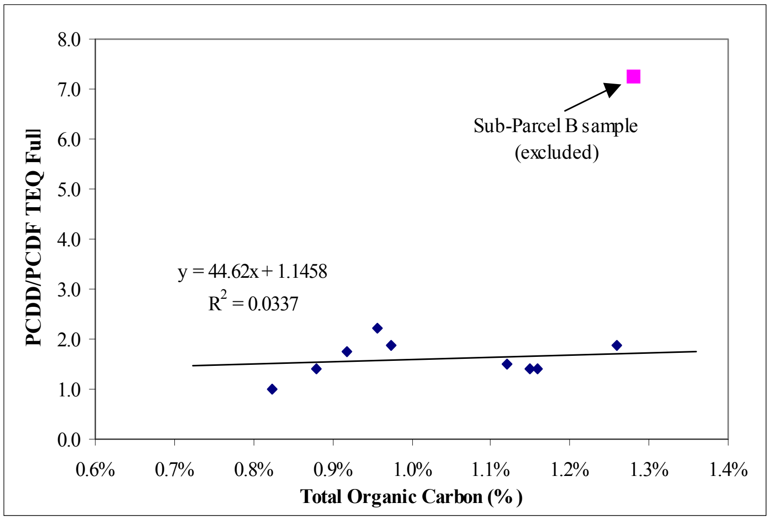
Figure 6 summarizes the relationship between Full TEQ(D/F) and soil TOC and soil particle size distribution (as reflected in the fraction passing the coarse and fine sieves) at the WTP. Similar results are obtained for Quant TEQ(D/F). As seen in the upper panel, TOC values range from about 0.8-1.3% in the WTP soil samples. TEQ (expressed as Full TEQ for dioxins and furans) tend to range from about 1-2 ppt, and the slope of the line through the data (excluding the value for sub-parcel B) is not statistically different from zero ($p > 0.5$). This suggests that the TEQ value in a soil sample is not strongly dependent on the TOC of that sample, at least within the narrow range of soil conditions that occur in the WTP. The sample from sub-parcel B (which has the greatest TEQ value) also has the greatest TOC value (12.8 g/kg), but the TOC value in sub-parcel E is nearly as high (12.6 g/kg) and the Full TEQ is within the typical range (3.5 ppt) for the site, suggesting that the high value is not likely to be attributable to the TOC content alone.

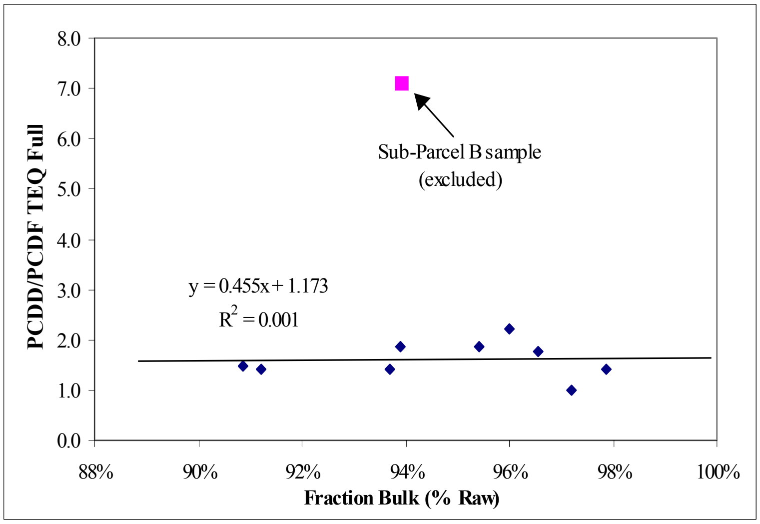
Figure 6 also shows the relation between Full TEQ(D/F) and the mass fraction of the raw field sample that passes a coarse screen (middle panel) or a fine screen (lower panel). As seen, there is no apparent relationship (either with or without the value for sub-parcel B) for either size class ($p > 0.5$), suggesting that soil particle size distribution is not an important determinant of TEQ, at least over the narrow range of soil conditions that exist at the WTP.

5.0 SUMMARY AND CONCLUSIONS

Figure 7 summarizes the key findings of this study. The upper panel compares EPA's current risk-based guideline for residential soil (1,000 ppt TEQ) to the mean concentration of Full TEQ concentration of PCDD/PCDF congeners in the WTP (about 2 ppt), along with the estimated mean levels in open space areas around the greater Denver area and in rural areas from locations reported in the literature. The lower panel displays the same data, except that ranges are shown rather than means, and the data are displayed on a log-scale. These findings indicate that there is no specific source of dioxin release in the WTP, and that dioxins in surface soil at the WTP are not of human health concern.

Figure 6. Relation Between TEQ and Soil Characteristics





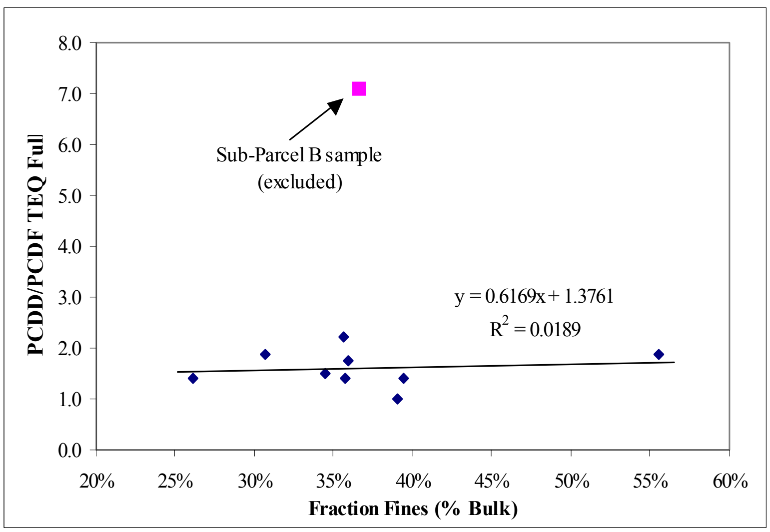
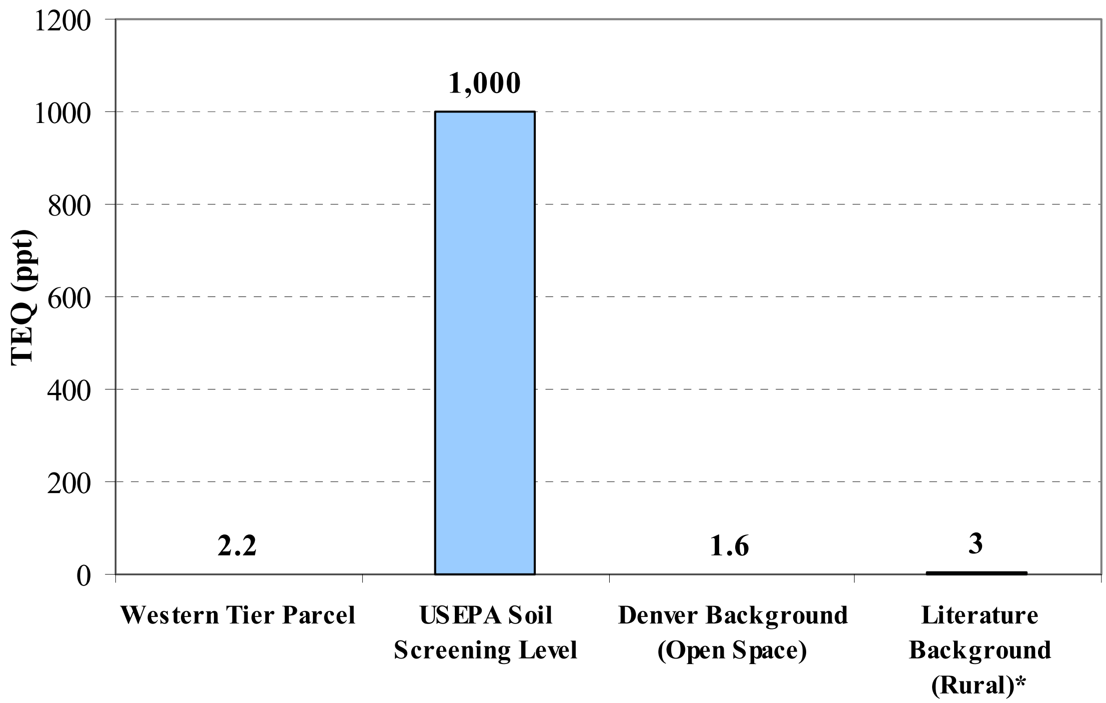
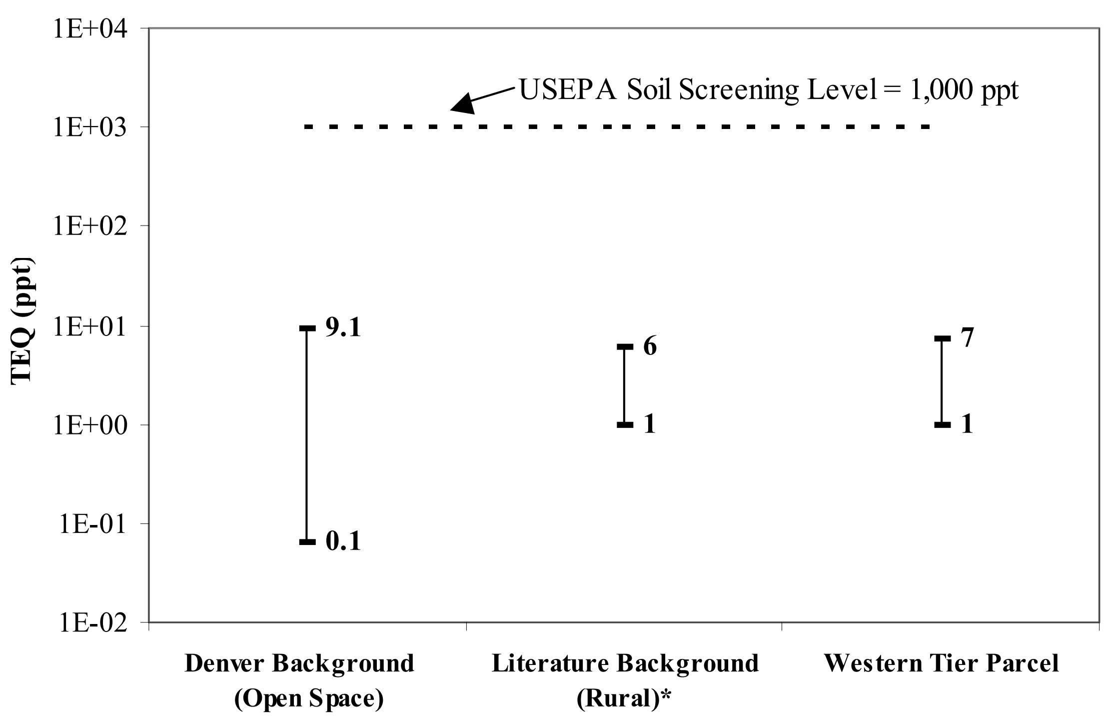


Figure 7. Summary of Results for WTP



* Approximate values



* Approximate values

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